



Utilizing Satellite Imagery for Seasonal Trophic Analysis in the Freshwater Reservoir

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Abstract

Eutrophication, an aquatic problem that impacts water quality and ecosystems, can be addressed through technological developments utilizing satellite imagery to analyze the trophic status of water. This study aimed to determine the trophic status of the freshwater reservoir in different seasons using satellite imagery. Water quality data were obtained from field surveys (11 samples) during the wet and dry seasons in Cirata Reservoir (Indonesia) while the remote sensing images were obtained from the Landsat-8 OLI. Trophic status refers to Carlson's Trophic State Index consisting of two parameters named chlorophyll-A and water transparency. This study found that satellite imagery could estimate seasonal trophic information. During the wet season, the algorithms determined information about chlorophyll-A (48%) and transparency (35%). Whereas during the dry season, the algorithms successfully estimated both information at 59% and 21%, respectively. Unfortunately, the Landsat-8 OLI had limitations for estimating total phosphorus. From these two parameters, the trophic status in the Cirata Reservoir showed moderate (wet season) and mild (dry season) eutrophic. Cirata Reservoir has a higher trophic level during the wet season since it has more surface water supply with lots of pollutants.

Keywords: Cirata, Landsat-8 OLI, remote sensing, surface water, water quality

1. INTRODUCTION

Cirata Reservoir is a multi-purpose water body located in West Java Province that functions in the hydroelectric power plant, flood control, irrigation, fishery production, and tourism [1]. The water quality is strongly influenced by various factors such as seasons, land use variation, and inland fishing activities [2]. The Citarum watershed, including the Cirata Reservoir, is heavily impacted by various industrial, agricultural, and residential activities, particularly in the Greater Bandung area upstream [3]-[5].

Water quality in Cirata Reservoir is continuously declining, and wastewater from anthropogenic activities triggers eutrophication. This eutrophication phenomenon results in higher nutrient levels from organic and inorganic materials in the water body [6]. Eutrophication is the main cause of algae blooms. Consequently,

phytoplankton abundance endangers aquatic ecosystems [7]. Negative impacts from this phenomenon are known by decreasing dissolved oxygen, appearing toxic compounds from biomass decomposition, increasing water turbidity, and reducing other environmental carrying capacities [8].

Eutrophication monitoring is important in managing the aquatic ecosystem and achieving sustainable development. The symptoms could be observed through the trophic status analysis [9]. Eutrophication analysis involves studying water quality parameters like chlorophyll-A, water transparency, and total phosphorus, which are typically collected through field surveys. These parameters are essential for determining eutrophication using Carlson's trophic state index (TSI), developed in 1977 [10]-[12]. Monitoring trophic status in water bodies has several challenges in cost, time, and human resources, especially if researchers want to monitor large water areas regularly. TSI generally employs three water quality parameters encompassing physical, chemical, and biological aspects, however, this method permits the utilization of solely two parameters [13].

With geospatial technology, some water quality parameters can be detected using remote sensing imagery. Widiawaty et al. reported that Landsat series imagery could observe changes in total suspended solids (TSS), chlorophyll-A, salinity,

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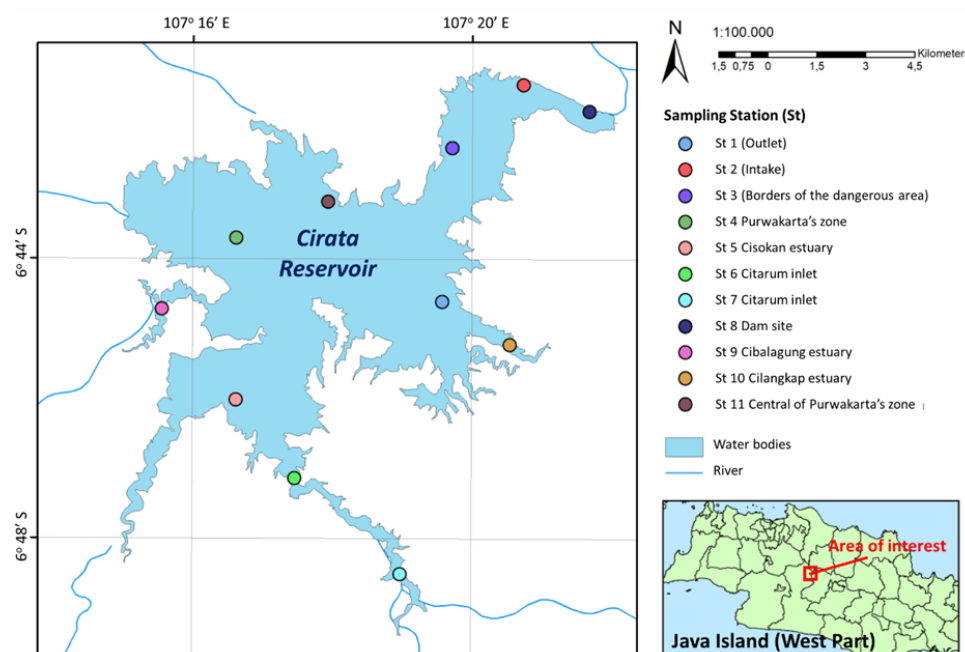


Figure 1. Sampling distribution in the Cirata Reservoir.

and surface temperature after human intervention in the aquatic ecosystems [14]. The use of remote sensing does not only rely on spectral reflectance, but also chromaticity analysis which could reveal chlorophyll-A, organic matter concentrations, and TSS levels [15]. Susiati et al. revealed that remote sensing was able to produce accurate information about water quality, as they used MODIS to observe TSS in tropical waters [16]. On a large scale, satellite-based remote sensing imagery is very effective for monitoring the changes in water quality and pollution because it provides raster data with different times of acquisition [17][18].

Despite the importance of monitoring pollution outbreaks, there is currently a lack of studies that provide seasonal trophic analysis using remote sensing data for Cirata Reservoir [19]. Other research using remote sensing imagery in Indonesia is limited to observing TSS [20], water bodies dynamics [21], also changes in DO, BOD and pH [22]. This study differs from previous research as it focuses on analyzing the seasonal trophic status of the freshwater reservoir using remote sensing data. The objective of this research is to gain a better understanding of the eutrophication issue in the Citarum watershed, which poses a significant threat to both the local community and the ecosystem.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling Procedure

This research is located in the Cirata Reservoir, West Java, Indonesia. Cirata Reservoir is one of 3 (three) artificial lakes in the Citarum River cascades besides Jatiluhur and Saguling, which has 6,200 ha area with an active volume reaching 796 million m³ [21][22]. Based on the Regional Regulation of West Java Province 39/2000, the Cirata Reservoir designation of groups C and D whose water quality must always be meet for fisheries, livestock, agriculture, urban businesses, industry, and hydropower [23]. The benefits of Cirata Reservoir require monitoring regularly to keep its function remains optimal [24][25].

Checking water quality through field surveys is certainly not efficient if it takes monthly or seasonally, although the Cirata Reservoir is threatened by eutrophication and pollution. In this research, field measurements have been carried out for two seasons (wet and dry) involving 11 sampling points as a basis to create new algorithms as shown in Figure 1. This sampling intends to measure two parameters of Carlson's TSI such as chlorophyll-A and water transparency. Chlorophyll-A was taken horizontally from the water bodies, and then the samples were put into opaque bottles and coolboxes to avoid photosynthesis [26]-[28].

Table 1. Trophic status for freshwater ecosystem.

Value	Information
≤ 30	Ultra oligotrophic
31–40	Oligotrophic
41–50	Mesotrophic
51–60	Mild eutrophic
61–70	Moderate eutrophic
71–80	Severe eutrophic
> 80	Hyper eutrophic

Sampling time, ideally, must be within ± 3 hours relative to the scheduled satellite recording to Earth. Chlorophyll-A data was obtained from the spectrophotometric or colorimetric analysis, while water transparency referred to Secchi disk transparency [29][30]. Due to limited data availability from the field surveys, this study did not include the analysis of total phosphorus parameters [31][32].

2.2. Methods

2.2.1. Imagery Processing

The Landsat-8 OLI, Operational Land Imager, satellite imagery came from the United States Geological Survey (official website), Cirata Reservoir was on path 122 and row 65. Satellite imagery needs a radiometric correction and masking process to produce specific-accurate data [33]. Radiometric correction adjusts digital numbers to reflectance values considering the sun's angle (top of atmosphere), while masking separates objects to match the study area [34]. Information extraction for the two water quality parameters referred to the band rationing method [35]. In this study, there were only three types of bands (B) to

determine Carlson's TSI, i.e., B2 (blue), B3 (green), and B4 (red) [36].

The relationship between satellite imagery data and the three Carlson's TSI parameters is known from the linear regression test, whereas the accuracy referred to r-square (R^2), significance level (p-value), and root mean square error (RMSE) with 95% confidence level [37]–[39]. The model with the highest R^2 value and significance will be chosen for compiling these parameters for each pixel, while RMSE provides insight into the extent to which the models correspond to the actual situation [40]. The regression model and RMSE are calculated using Equations 1-2;

$$Y = aX + b \quad (1)$$

$$RMSE = \sqrt{\frac{\sum(Y_i - \hat{Y}_i)^2}{n}} \quad (2)$$

whereas Y is the dependent variable (observed value), X is the independent variable (band values), a is the regression coefficient, b is a constant, RMSE is the value of root mean square error, \hat{Y}_i is the predicted value (estimated), i is the data identity, and n is the number of samples.

2.2.2. Trophic Analysis

The algorithms selected for tropic analysis are based on the best statistical criterion because the testing results served the most suitable spectral information with the field data [41]–[43]. The tropic analysis is composed of two algorithms to express Carlson's TSI which were regression models (Equation 3). Two algorithms consisting of chlorophyll-A and transparency in the Cirata Reservoir are shown in Equations 4-5. Mapping the trophic status using satellite imagery integrates spatial data to accurately reflect the actual conditions, enabling geospatial representation

Table 2. Algorithms for modeling the Carlson's TSI.

Parameter	Wet Season	Dry Season
Water transparency (m)	$\ln SDT = -2.223 + 0.843 \times (B2/B4)$ $R^2 = 0.39$ (p-value 0.03)	$\ln SDT = -1.387 + 0.455 \times (B2/B4)$ $R^2 = 0.21$ (p-value 0.13)
Chlorophyll-A ($\mu\text{g/L}$)	$CA = 93.149 - 92.142 \times (B2-B4)/B3$ $R^2 = 0.48$ (p-value 0.01)	$CA = 21.428 - 31.671 \times (B2-B4)/B3$ $R^2 = 0.59$ (p-value < 0.01)

Note: SDT is the water transparency value and CA is the chlorophyll-A value

through color-coded classifications that make it easier to understand the phenomena [44]. A trophic status category is known from the value conversion of Carlson's TSI with reference to Table 1 [45][46];

$$\text{Carlson's TSI} = 0.5 (\text{TSI CA} + \text{TSI SDT}) \quad (3)$$

$$\text{TSI CA} = 9.81 \times \ln(\text{CA}) + 30.6 \quad (4)$$

$$\text{TSI SDT} = 60 - 14.41 \times \ln(\text{SDT}) \quad (5)$$

whereas TSI is the trophic state index, CA is the chlorophyll-A value, SDT is the transparency value, and \ln is the natural logarithm.

3. RESULTS AND DISCUSSIONS

3.1. Algorithms Development

Chlorophyll-A was identified as a parameter that has optimal R^2 value in two seasons, 48% (wet season) and 59% (dry season). This shows that the composition of blue, red, and green bands is good for explaining variations in chlorophyll-A changes at Cirata Reservoir. Chlorophyll-A tends to absorb blue and red, as well as reflect green, and the predictor had a strong correlation with this parameter [47]. However, the regression analysis for the water transparency parameter showed low R^2 when compared to chlorophyll-A. Band ratio between blue and green bands can only explain 39% of water transparency during the wet season, and 21% during the dry season. The regression equation and R^2 values for each parameter are

shown in Table 2.

Despite not achieving a high R^2 , both algorithms for the respective parameters demonstrated relatively low errors. RMSE for the transparency parameter was 0.14 m (wet season) and 0.09 m (dry season). Meanwhile, RMSE for the chlorophyll-A parameter reached 10.9 $\mu\text{g/L}$ (wet season) and 3.4 $\mu\text{g/L}$ (dry season). Both RMSEs were low and indicated that regression equations are not too far off from the actual data [48]. The smaller RMSE in an algorithm for predicting the actual values, indicating that they are suitable for use as an estimation model [49]. The analysis of R^2 and RMSE reveals that the accuracy of trophic status estimation is influenced by seasonal variations.

3.2. Trophic Status

Cirata Reservoir's status is indicated by the color brightness level which describes the water transparency. The brighter color showed a higher value and vice versa (Figure 2). In both seasons, most water, especially the middle part of the Cirata Reservoir belongs to the moderate eutrophic. Moderate eutrophic status during the wet season was 91.99%, while during the dry season was 68.35%. There are several variations in water transparency in the central region of the Cirata Reservoir. Severe eutrophication is characterized by excessive nutrient enrichment of water bodies, leading to the rapid growth of algae and other aquatic plants, this mainly occurs in areas near

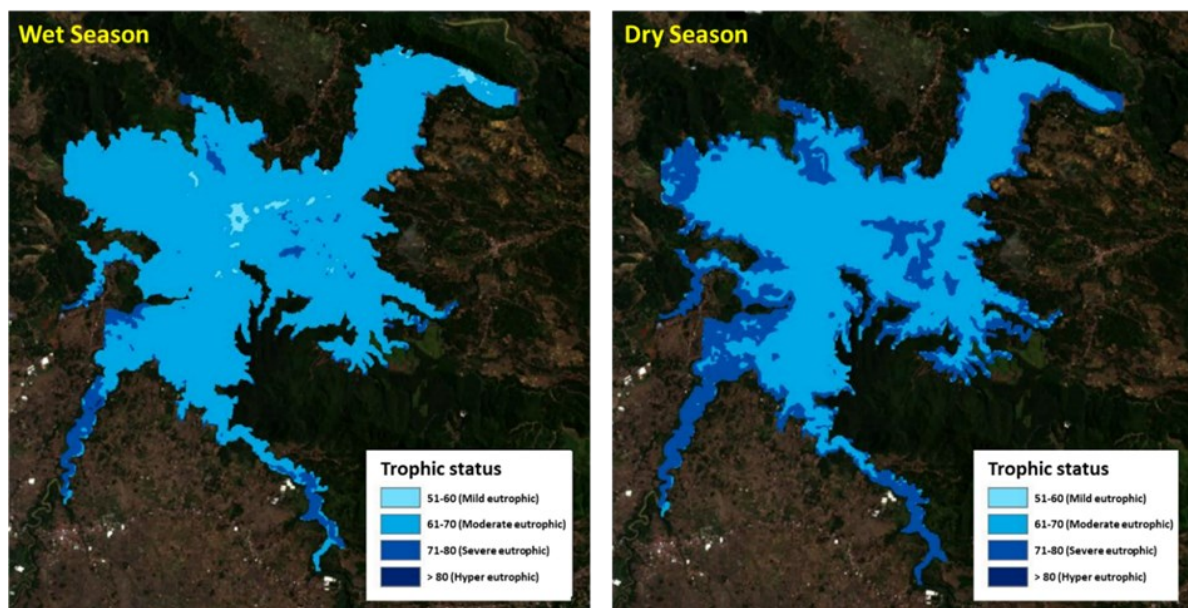


Figure 2. Water transparency in the Cirata Reservoir.

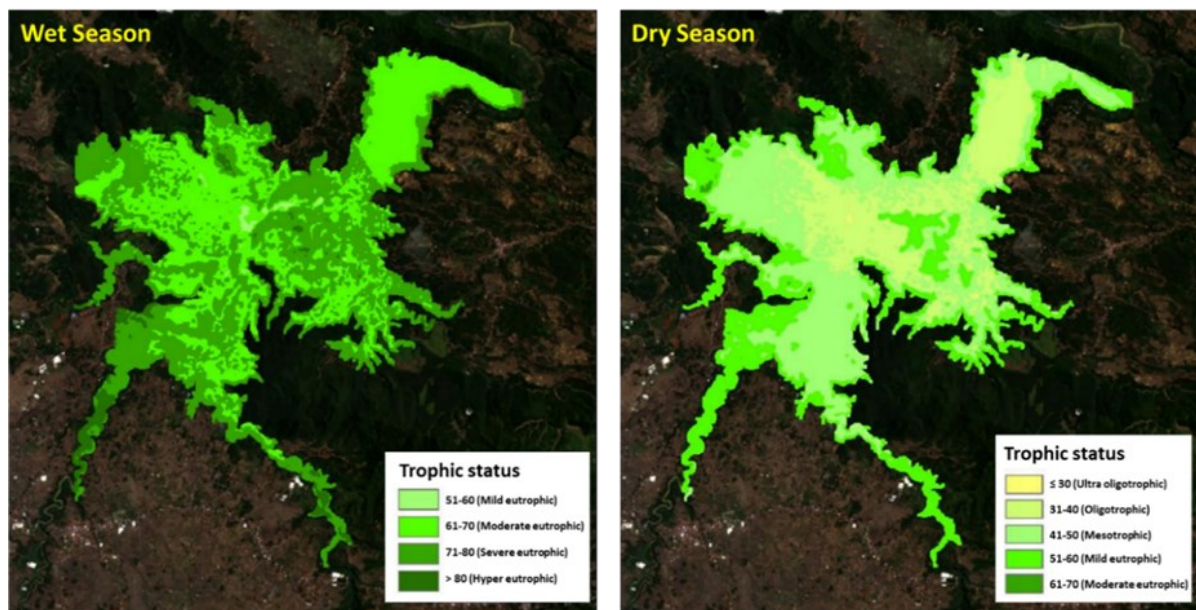


Figure 3. Chlorophyll-A in the Cirata Reservoir.

estuaries where the water surface is shallower and sediments are high [50][51]. During the dry season, decreasing water volume also caused low water transparency around the reservoir banks. Hypereutrophic were observed during the wet season, however, the total area with severe eutrophic and hypereutrophic was only 6.86%. During the dry season, it was identified that a significant eutrophic condition covers 31.65% of the area. On the water transparency parameter, the trophic level tends to be higher in the dry season than in the wet season.

Meanwhile, the chlorophyll-A distribution in the two seasons showed differences according to selected algorithm results (Figure 3). During the wet season, the trophic conditions in the Cirata Reservoir are dominated by mild and moderate eutrophic levels. Chlorophyll-A is a phytoplankton's pigment, which indicates their abundance in waters [52]. In waters with sufficient nutrients and sunlight exposure, phytoplankton grows faster [53]. The phytoplankton growth is high in almost all reservoirs during the wet season. During the dry season, chlorophyll-A is lower, since the water supply from the river and its surrounding area is reduced. During the wet season, more than 50% of the waters are in moderate to severe eutrophic based on chlorophyll-A values.

3.3. Carlson's TSI

The maps depict a combined spatial distribution

based on trophic parameters in each season (Figure 4). Trophic conditions in the Cirata Reservoir during the wet season were dominated by moderate eutrophic. Meanwhile, during the dry season, water is at a mild eutrophic level. The trophic level is generally higher during the wet season than the dry season, as shown in Table 3. The distribution maps indicate that the Cisokan and Citarum rivers have higher trophic levels compared to other areas. This phenomenon reflected high erosion that supplies sediment, nutrients, and pollutants from the watershed processes [54].

In the middle area of the Cirata Reservoir, there is a lower trophic status, especially during the dry season because the river flows and discharge are less. This situation is common and belongs to annual fluctuations, thus the sediment that enters the waters does not reach the middle area of the reservoir [55]. Carlson's TSI in the Cirata Reservoir is a spatial information because it can provide location details for each trophic level. This analysis helps in identifying the time and place contamination due to eutrophication, which benefits for the management of a sustainable reservoir ecosystem. However, this devised algorithm has a weakness because the coefficient of determination is not consistent for two seasons. Therefore, the estimation model of each parameter must be carried out more carefully.

Cirata Reservoir's trophic status in the wet and dry seasons has different conditions for each

Table 3. Trophic status coverage in the Cirata Reservoir based on Carlson's TSI.

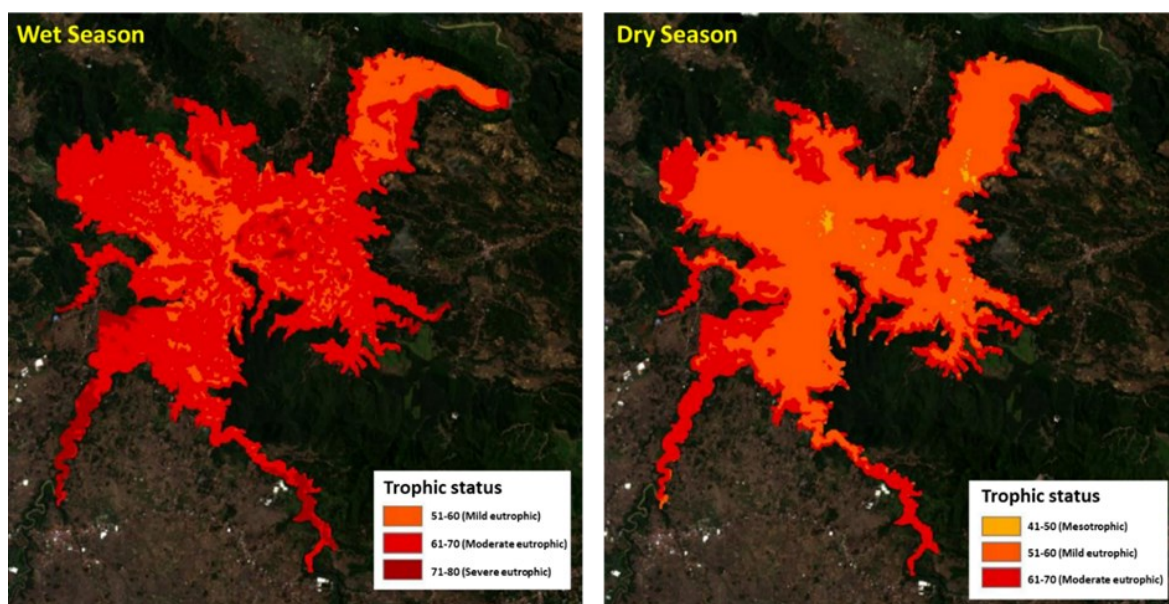
Season	Status	Area	
		Ha	%
Wet	Mild eutrophic	1186.02	18.66
	Moderate eutrophic	4736.16	74.50
	Severe eutrophic	435.24	6.85
	Mesotrophic	37.35	0.59
Dry	Mild eutrophic	4167.81	65.56
	Moderate eutrophic	2152.26	33.85

parameter. Water transparency showed moderate eutrophic dominance during both seasons. This is different from chlorophyll-A, which showed moderate eutrophic during the wet season, but mesotrophic during the dry season. The abundance of phytoplankton tends to increase because nutrients from the land enter the reservoir through rainwater, run-off or upwelling [56]. High rainfall leads to a decrease in water temperature and reduces agitation in the depth column [57]. During the wet season, high rain intensity increases nutrients entering the waters through sediments carried by overflowing river water and run-off [58]. In addition, changes in chlorophyll-A are also influenced by sunlight in certain seasons [59][60].

River flow is a sediment transport route that carries nutrients, in turn, increasing the trophic level [61]. The daily organic load entering the Cirata

Reservoir from the Citarum and Cisokan Rivers is 2,210.318 kg/day and 855.797 kg/day, respectively [62]. The central area of the reservoir is a transition zone with low water velocity and long residence time [63]. A long residence time indicates that the amount of water entering or leaving the river flow into the central area of reservoir is relatively small [64]. Residence time is a period when the sediment particles are temporarily in a water storage [65]. As a result, the trophic level tends to be higher during the wet season, rather than during the dry season.

Objects in waters such as phytoplankton and dissolved nutrients have the ability to reflect spectrum colors [66]. The algorithm for water transparency has an anomaly because aquatic objects that reflect the red band are disrupted by freshwater aquaculture activities (floating net cages) [67]. The number of floating net cages in

**Figure 4.** Trophic status in the Cirata Reservoir.

Cirata Reservoir has reached more than 98,000 units, which existence has exceeded the maximum limit of 7,000 units [68]. In addition, the surface waters are also blocked by hyacinths (*Pontederia crassipes*) [69][70]. Due to the cultivation activity on the water surface, the red band reflection is suboptimal, hindering the satellite sensor from accurately capturing the original reflectance. The surface reflectance value is the main component in analyzing phenomena using the optical-based remote sensing data [71]. Despite obstructing the geospatial observations, the contamination of the leftover feed due to improper dosage is another threat to the electricity generator in Cirata and encourages accelerated hyacinths growth that covers the water surface [72].

The limited capacity to accurately estimate aquatic phenomena, including the case of Cirata Reservoir, through remote sensing poses a significant challenge in conducting research on ecosystem sustainability in Indonesia. Trisakti et al. noted that the utilization of satellite data for monitoring lake ecosystems in this country remains limited and challenging due to operational constraints [73]. One of the main obstacles is the lack of standardization, processing procedures, and the resources in finding robust algorithms [74]. The lack of extensive testing in diverse settings directly impacts the applicability of the algorithm model, limiting its effectiveness to specific conditions [75]. Even though the algorithms for monitoring trophic parameters and Carlson's TSI are just an estimation model, those algorithms are useful in a preliminary assessment with minimum error.

4. CONCLUSIONS

Landsat-8 OLI has proved to be capable for analyzing ecosystem dynamics in the Cirata Reservoir. The R^2 values for all parameters in both seasons indicated that the spatial distribution model is well-suited to estimate Carlson's TSI. In this study, the algorithms utilizing Landsat-8 OLI and field data demonstrated higher accuracy in predicting chlorophyll-A compared to water transparency. The coefficient of determination for chlorophyll-A during the wet season is lower than during the dry season. The transparency of the water shows the same situation as the Carlson TSI

showing moderate eutrophic during the wet season and mild eutrophic during the dry season. Therefore, the trophic status of the Cirata reservoir tends to be higher during the wet season. Although the algorithm is capable of estimating Carlson's TSI, this research is limited by small samples and annual seasonal changes. Further efforts are necessary to enhance similar research by incorporating additional field data and observation sensors.

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Conflicts of Interest

The author(s) declare no conflict of interest.

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